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(54) Wavelength-independent fused fibre power divider

(57) A wavelength-independent fused fibre power divider with a single input and a plurality of outputs is made by a method comprising fusing a plurality of fibres (1 - Fig. 1) into a coupler structure with an adiabatic taper (3) at each end of the coupling region (2) by a differential pulling technique, cleaving the coupler structure into two parts at the coupling region, fusion splicing a single core fibre (6) of matched diameter to the cleaved end of one coupler structure part (5), and tapering the fusion splice (7) to produce adiabatic tapers (9) and a waist section (8), which latter step has the effect of reducing modal field mismatch across the splice (Fig. 4).

Fig.1.

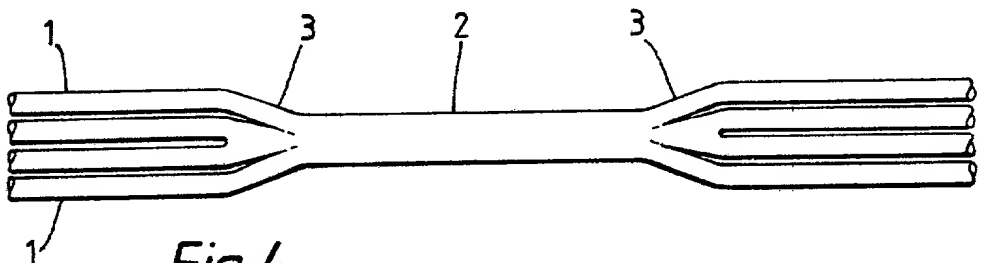
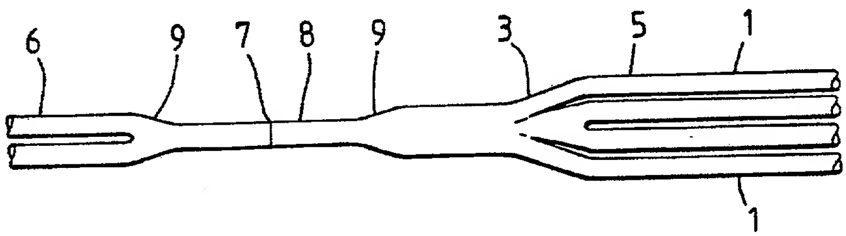


Fig.4.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig.1.

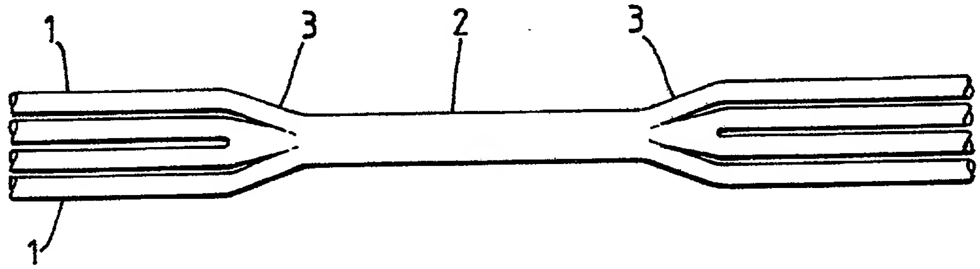


Fig.2.

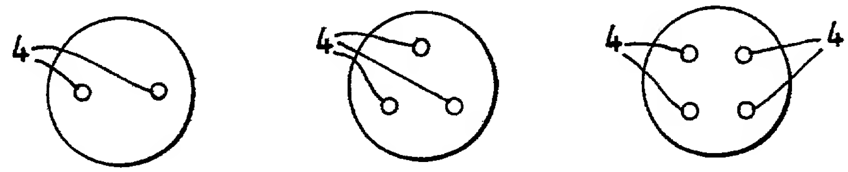


Fig.3.

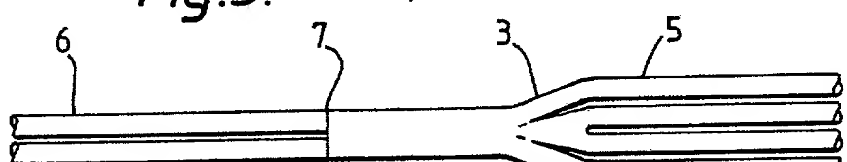
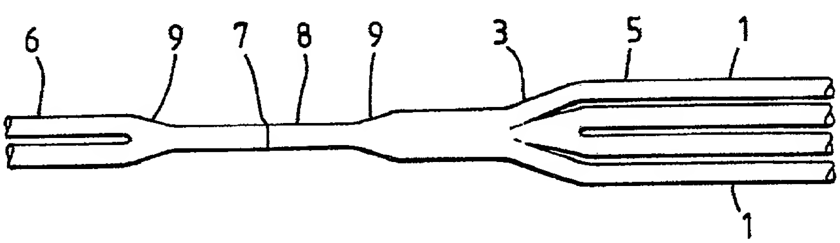


Fig.4.



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FIBRE COUPLERS

This invention relates to fibre couplers and in particular to fibre power dividers.

A conventional form of single mode fibre coupler is the fused biconical taper coupler which may be constituted by two or more single mode optical fibres which have been fused together and progressively stretched, such as by the differential pulling technique disclosed in our GB Patent Specification No. 2 150 703B, to which attention is directed. Such a fused adiabatically tapered coupler thus has two or more input ports and two or more output ports and may be used as a distributive component in optical fibre systems such as optical local area networks and data highways. In such a system a single mode multiport coupler may be employed as a "tree" coupler, by which term is meant a coupler with a single input port and a set of output ports between which an input signal is distributed. A multiport coupler made by fusing a plurality of fibres together as described above has a plurality of input ports as well as a plurality of output ports. In a 2x2 fibre coupler, for example, excitation of a mode in the fibre coupled to one input port will excite two modes at the coupling region and coupling results from interference between these two modes. The operation of the coupler is, therefore, wavelength dependent.

Wavelength-independent couplers are desirable for various applications, particularly spectral measurement and wavelength multiplexed systems.

It has previously been suggested by Qian ("A new idea for wavelength insensitive fibre couplers" I.E.E.Colloqium on Advanced Waveguide Devices, 20 May 1986) that if only the fundamental guided mode of the coupling region is excited then no modal "beating", that is wavelength dependent, effects occur. Qian thus proposed that only the first mode is the coupling region be excited significantly, whilst the second mode is either negligibly excited or is cut-off. Thus a 1x2 coupler rather than a 2x2 coupler was involved.

Due to the absence of interference the power division between the two output arms and ports depends only on the power distribution at the end of the coupling region and is wavelength insensitive. The operating principle of such 1x2 couplers is in common use in the field of planar waveguides, for example $LiNbO_3$ devices, as the basic Y-junction power divider. It has been proposed by Minelly and Hussey ("A single mode fibre Y-junction beansplitter" Electronic Letters Vol.23,p 1087, 1987) to produce such a wavelength independent device as a fused device. The method employed involved cleaving a 2 x 2 fused fibre coupler and splicing one half to a pre-tapered input optical fibre to produce a Y structure with one input and two output ports. The mode excited in the input fibre is initially strongly confined to the core of the input fibre but it spreads out as it propagates along the input taper. At some point along the taper the field becomes bound at the strongly guiding cladding/air boundary and provided that the core is now sufficiently small this boundary then dominates the guidance of the mode. The light propagates across the splice point and the adiabatically increasing cores at the output (fork) side of the junction guide power equally into the two outputs for all wavelengths, irrespective of external index and polarisation. The modal field mismatch at the splice gave large device losses of the order of 1.5dB.

Such losses are unacceptably high for "tree" coupler/power divider applications where many such power divisions will be encountered, such as optical fibre connections in telephone systems where the optical fibre is brought closer to the telephone subscribers than hitherto if not directly to the subscribers apparatus.

It is believed that couplers/dividers with acceptable loss values have never been successively achieved with the manufacturing method employed by Minelly and Hussey, and it is an object of the present invention to provide a method which results in power dividers with improved loss levels.

According to one aspect of the present invention there is provided a method of manufacturing a wavelength-independent fused fibre power divider having a single input and a plurality of outputs, including the steps of fusing a plurality of fibres together to form a coupler structure having an adiabatic taper at each end of a coupling region of uniform circular cross-section, cleaving the coupler structure into two parts at the coupling region, forming a fusion splice between a single core fibre, of the same diameter and cross-section as the coupling region, and the cleaved end of one coupler structure part, and tapering the fusion splice whereby to reduce modal field mismatch.

According to another aspect of the present invention there is provided a method of manufacturing a wavelength-independent fused fibre power divider having a single input and a plurality of outputs including the steps of assembling a plurality of fibres together into a bundle of a first diameter and fusing the fibres together over one length section of the bundle with an adiabatic taper between the one length section and the remainder of the bundle, the one length section being of uniform circular cross-section, of a second diameter which is smaller than the first diameter and having an end remote from the taper, forming a fusion splice

between said end and a single core fibre of the uniform circular cross-section and the second diameter and tapering the fusion splice whereby to reduce modal field mismatch thereat.

According to yet another aspect of the present invention there is provided a wavelength-independent fused fibre power divider having a single input and a plurality of outputs, wherein the single input is comprised by a single core optical fibre, wherein the plurality of outputs is comprised by a bundle of single core optical fibres which are fused together at a coupling section with a first adiabatic taper between the coupling section and another section of the bundle, wherein an end of the coupling section remote from the first adiabatic taper is fusion spliced to an end of said single core optical fibre of matched diameter and cross-section, the diameter over a length region including the fusion splice being less than the matched diameter of the single core fibre and the coupling section, there being a adiabatic taper at each end of said length region including the fusion splice.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which

Fig. 1 illustrates schematically a fused tapered 2 x 2 coupler

Fig. 2 illustrates, on an enlarged scale, the cross-section of the coupling region of fused tapered N x N couplers for N=2, 3 and 4.

Fig. 3 illustrates one half of the 2 x 2 coupler of Fig. 1 fusion spliced to a single fibre of matched diameter directly after splicing, and

Fig. 4 illustrates the spliced arrangement of Fig. 3 following tapering of the fused splice region.

The known method of manufacture employed by Minelly and Hussey results in large device losses due to

modal field mismatch across the splice despite their attempts to ensure matching.

We have found that the modal field mismatch can be reduced by tapering the spliced junction following splicing. For this to be achieved successfully the two fibre elements being spliced need to be very closely matched in diameter, for similar dopant levels in the fibres. Thus if a 1 x N device is to be tapered subsequent to splicing it is necessary to have good control over the diameter of the fused waveguide (coupling region) formed by fusing the N fibres together. Such control is afforded by the differential pulling technique which is the subject of our aforementioned Patent specification.

Referring now to Fig. 1 the first step in the fibre power divider fabrication method according to one embodiment of the present invention comprises making a coupler structure by taking the requisite number of fibres as there are to be power outputs, and using our progressive differential pulling technique to fuse the fibres together and provide a reduced diameter central region, with adiabatically tapered sections at each end of the central section. In Fig. 1 two fibres 1 are illustrated as so fused and adiabatically tapered, the central region having reference numeral 2 and the tapered sections reference numeral 3. The central region 2 is parallel sided. The fibres are fused together to a uniform circular coss-section over the central region. Examples of this cross-section for two, three and four fibres are illustrated in Fig. 2. Reference numeral 4 indicates the cores of these fibres.

The fused coupler structure is then cleaved in the uniform cross-section central region into two parts and one part 5 is replaced by a single core fibre 6 of matched diameter which is fused thereto, to produce the structure illustrated in Fig. 3 with a splice at 7.

The fused splice region is then tapered to produce a structure as illustrated in Fig. 4 which has a further reduced diameter (waist) section 8 and adiabatic tapers 9. The tapering may be produced using our progressive differential pulling technique but this is not the only possible technique. Using the process described above, wavelength independent 1 x N fused fibre power dividers can be achieved with negligible losses.

In order to provide the single core fibre 6 of matched diameter it may be necessary to pre-taper a single core fibre to the appropriate size. Such pretapering may be achieved also by our aforementioned differential pulling technique, which produces adiabatic tapers and parallel-sided reduced diameter sections in an extremely controllable manner.

The power divider manufacture requires provision of a structure which consists effectively of one half of a coupler structure. The above described method involves producing a standard coupler structure and cleaving it into two parts.

Other methods of providing a structure equivalent to one "half" of a coupler structure may be possible. In general terms, a bundle of optical fibres simply need to be fused together at one end, which one end is then reduced in diameter by a technique providing an adiabatic taper between the reduced diameter end and the rest of the bundle.

CLAIMS

1. A method of manufacturing a wavelength-independent fused fibre power divider having a single input and a plurality of outputs, including the steps of fusing a plurality of fibres together to form a coupler structure having an adiabatic taper at each end of a coupling region of uniform circular cross-section, cleaving the coupler structure into two parts at the coupling region, forming a fusion splice between a single core fibre, of the same diameter and cross-section as the coupling region, and the cleaved end of one coupler structure part, and tapering the fusion splice whereby to reduce modal field mismatch.

2. A method of manufacturing a wavelength-independent fused fibre power divider having a single input and a plurality of outputs including the steps of assembling a plurality of fibres together into a bundle of a first diameter and fusing the fibres together over one length section of the bundle with an adiabatic taper between the one length section and the remainder of the bundle, the one length section being of uniform circular cross-section, of a second diameter which is smaller than the first diameter and having an end remote from the taper, forming a fusion splice between said end and a single core fibre of the uniform circular cross-section and the second diameter and tapering the fusion splice whereby to reduce modal field mismatch thereat.

3. A method as claimed in claim 1 or claim 2 wherein the fusion splice is tapered by a differential pulling technique.

4. A method as claimed in any one of the preceding claims wherein the fibres are single mode fibre.

5. A method as claimed in any one of the preceding claims and including the step of pre-tapering a fibre to form said single core fibre of uniform circular cross-section and the requisite diameter.

6. A method as claimed in claim 1 wherein the coupler is manufactured by a differential pulling technique.

7. A method as claimed in any one of the preceding claims and for manufacturing a single input - two output power divider.

8. A wavelength-independent fused fibre power divider having a single input and a plurality of outputs manufactured by a method as claimed in any one of the preceding claims.

9. A wavelength-independent fused fibre power divider having a single input and a plurality of outputs, wherein the single input is comprised by a single core optical fibre, wherein the plurality of outputs is comprised by a bundle of single core optical fibres which are fused together at a coupling section with a first adiabatic taper between the coupling section and another section of the bundle, wherein an end of the coupling section remote from the first adiabatic taper is fusion spliced to an end of said single core optical fibre of matched diameter and cross-section, the diameter over a length region including the fusion splice being less than the matched diameter of the single core fibre and the coupling section, there being an adiabatic taper at each end of said length region including the fusion splice.

10. A power divider as claimed in claim 9 wherein the fibres are single mode.

11. A power divider as claimed in claim 9 or claim 10 wherein the adiabatic tapers were formed by a differential pulling technique.

12. A wavelength-independent fused fibre power divider substantially as herein described with reference to Fig. 4 of the accompanying drawings.

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